A NEW MODEL OF PRESSURE PROPAGATION IN HUMAN TISSUE IN HIFU APPLICATION

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ABSTRACT

This project is a new pressure model for propagating pressure inside one or several tissues at the time of treatment with high intensity focus ultrasound (HIFU). Pressure's changes are converted to heat's changes in tissue and this is done oscillatory. When the treatment is done in deeper tissues, obtained heat can affect surficial tissues. This pressure effect also can enter surficial tissues. Amount of pressure and heat possible injury can be controlled and reduced through this mechanical modelling. In this model we have used three layers and pressure also is obtained within these three layers and is investigated averagely. Obtained tissue in this mood is kidney tissue and it is tried to obtain the rate of pressure in these three layers.

Key words: *Mechanical Index, Hifu (High Intensity Focus Ultrasound), Mechanical ModellingYour article has been received and it will be reviewed but the process could take several time.*

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Introduction

Ultrasound today is widely used for diagnosis in treatment process and monitoring. Cavitation is created continuously by HIFU waves around therapeutic area because of water. With implementing HIFU waves in to the created cavitation tissue which as its result the amount of pressure and then heat will be increased in tissue, this effect can cause destruction and damaging of tissue so controlling that by system is crucially important for us.

It is very important at the time of treatment with HIFU that bubbles to be monitored separately. Some believe that bubbles can produce heat therefor it is very important that pressure and heat are measured separately in this process.

Chang-Yu Hsieh et al could obtain its amount of pressure using a hydrophane from bubble approximate model(1).

Because of heat and bubble making effects at the time of treating with HIFU both lead to biological effects on tissue.

At the time of collision with the tissue, sound causes creating the effects of diffraction and scattering. A model can be proposed which obtain a bubble using KZK equation based on the amount of pressure. In this mood, wave's harmonics can be achieved. A probe is used in this situation which is placed on a phantom and the amount of pressure is obtained by a hydrophane that is in the center of probe's hypothetical line on phantom(2,3).

Propagating ultrasound's waves which depend on time inside a tissue like liver causes that pressure inside this tissue changes depending on the time as well. When pressure changes inside a tissue causes heat and biological effect on that. Heat and pressure propagation beside each other and beside blood vessels will be effective on tissue. The importance of monitoring two parameters will be cleared here. Solving bio-heat equations is very important for special tissue and its comparison with obtained heat. By using laser wave the number of bubbles can be counted and their diameter can be obtained as well. Shock waves which lead to creating bubble can be effective on the size of bubbles and also can be compared by available bubble equations[4,5].

Some studies have been done on sound non-linear propagation in cancer tissue by Zabolotskya and Sluyan where they mention on the effect of existing bubbles in water as non-linear resources and the factor of weakening sound in tissue. They investigated pressure's two dimensional propagation using KZK equations with this deduction[6].

Since the depth of destruction must be kept, ultrasound treatment in cancers will be important, sound waves produce mechanical energy and this mechanical energy affect one area. The amount of sound attraction also is important on increase of tissue heat that lead to sound bigness and coagulation in tissue. Investigating and controlling these waves' environmental effects in living tissue using Gaussian equations is absolutely important. A tumor tissue has different mechanical characteristics. Sonography and MRI methods are used for accurate perception of aspects and tumor tissue's mechanical characteristics[4].

Now we model body's tissue to mechanical elements. Now if a mechanical wave which is propagated from transducer and want to hit target tissue (tumor) to pass layers which are body's layers, its pressure gradually reduced and each layers' pressure can be obtained using this method. Layer's diameter isn't important in this model but layer's material is important[7].

This mechanical model which we proposed includes three elements of spring, damper and mass. Model entry is electrical signal like HIFU radiofrequency waves which produce primary electrical wave and then this electrical wave is converted to mechanical waves in mechanical space by mechanical convertors and in fact these mechanical waves pass elements. As these waves pass mechanical model, pressure and heat will be created. If this mechanical wave is focused on body's tissue instead of mechanical elements, it can increase heat and pressure in tissue. These mechanical elements' values can be replaced from kidney or liver's values and the obtained the amount of heat in one of these tissues.

The general structure of this paper will be followed that in part 2 the parts of designed model, part 3 tissue's mechanical model, part 4 results and work of laboratory, part 5 the advantages of this method and in part 6 the general results of this article are explained.

Materials and method

We have used MATLAB and Simulink toolbox software in this model. All elements are used from mechanical box like mass, spring and damper and also mechanical sensors are removed from this group for evaluating heat and pressure. For clinical work, a sheep's kidney tissue which has measured dimensions is used that its strain and shear stress values are obtained in laboratory devices, viscosity value is recorded for tissue and non-dependent variables on time are considered in this experiment, in case of considering correctly assumption is with time change, it is tried to be mention this problem in complementary experiments. Then by using this model or FDA (food and drug administration) software[8] which for simulating HIFU, the amount of pressure and heat is compared.

Introducing HIFU input signal

As it is shown in the figure, we use a source of electric waves in Simulink. First we used a sinusoidal source and in next step pulse and finally saw tooth damped signal. As we know HIFU signal is that very saw tooth damped signal that with implementing this signal to body's tissues, a destructive thing happens. So we consider signal PD, SPL as follows:

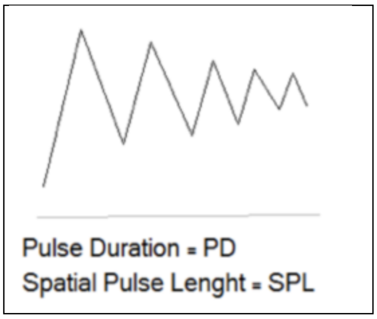

Figure 1: The figure of input wave at the time of implementing to HIFU probe for treatment.

For this pulse the changeable values of PD, SPL are based on below values:

SPL=n.λ[2]

PD=*n.T*[3]

That in these equations, SPL based on longitudinal dimension and PD based on Time dimension (spatial and temporal pulse length) are settable. In these equations there are n numbers of decaying pulse oscillation, T period pulse and λ the wavelength of an oscillation of the pulse.

If obtained electric signal of electric environment enters mechanical environment can be considered as generator of an ideal power source and this power was done on mechanical elements (mass, spring and damper). This mechanical power can be applied to first series elements as primary tissues' layer then second and third. In each layer because of the existence of weakening phenomenon, the amount of this power will reduce.

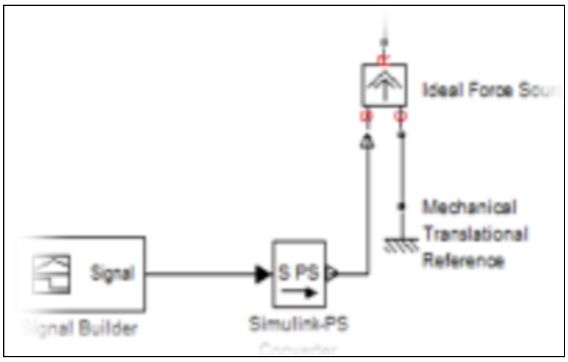

Figure 2: HIFU input electric wave before converting to mechanic waves.

Introducing model's components

Body's tissue is modeled as mechanical elements in this model. According to this model, spring as tissue elasticity and damper is considered as a resistant agent in front of spring and spring's fixator. Obtained power is stored as outcome in desired mass[7].

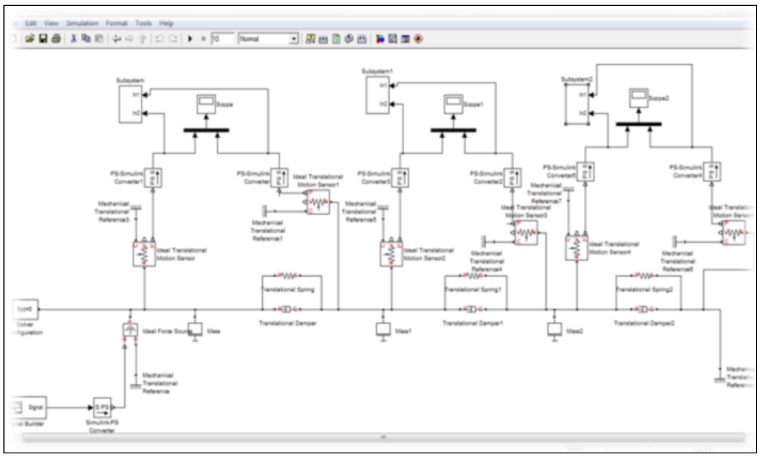

Figure 3: Modeling with Simulink using a sensor for achieving pressure in three different layers.

It is assumed here that one phantom or tissue includes three separated layers, the first and third layer are water and the middle or second one is kidney tissue. When mechanic wave passes each one of these three layers has different behavior, in this mood tissue is pressed in each layer (mechanical effect) and as result of this heat is produced.

The amount of heat and obtained pressure can be achieved using heat, pressure ideal sensors. If we use a perfect motion sensor in both head of mechanical element and reduce the amount of this motion, using figure 3 the amount of moving can be obtained as the effect of applying primary power. With twice derivative of motion parameter, acceleration is achieved. If the amount of pressure is multiplied in layer's mass, the amount of obtained power which is gained under the effect of applying acoustic waves will be obtained.

Component parameters of liver, kidney

We divide a sheep's kidney weighing 61.07 grams into four equal parts, dimensions and weight of each part based on measuring them with calipers and precision scale are shown as figure 4-5.

Figure 4: Sheep's kidney tissue without preservative and is divided into 4 parts with cutouts.

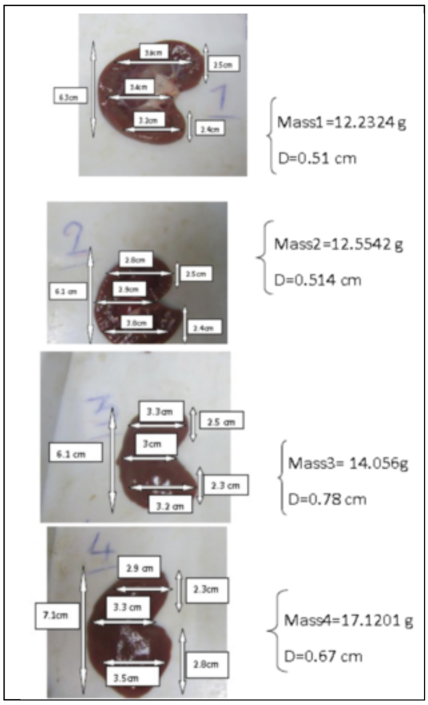

Figure 5: Dimensions, mass and weight of each Separated part.

Shear stress and strain graphs for a lobe with the system of Anton Paar symbolically are as follows. With putting the values of mass, spring and damper in figure 3, the amount of HIFU pressure on one tissue including a kidney's layer can be obtained.

In this phantom which is designed as follows, there is a layer of water and in the middle of that a layer of kidney tissue is floating:

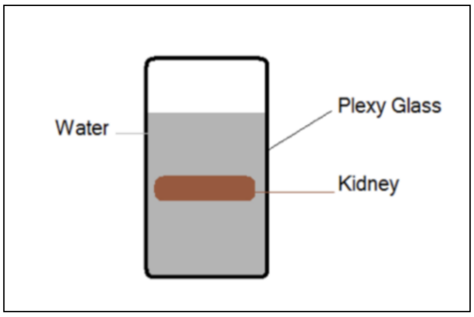

Figure 6: Assumed and valorized phantom for treating and simulating.

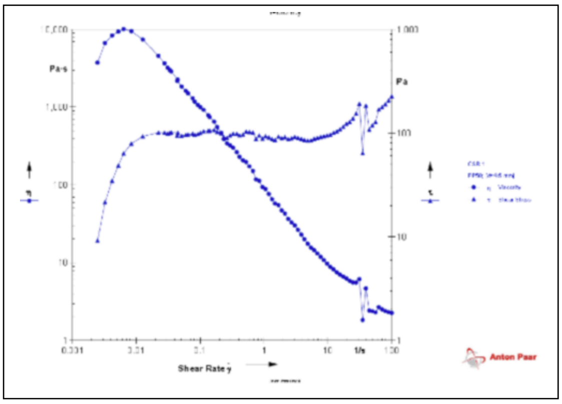

Figure 7: The shape of the strain and stress diagram for a tissue layer.

Experimental results

For investigating this simulating and existing simulating in FDA some points must be noticed; first this simulating is done with as transducer with standard and 3Ddimensions while in mechanical simulating, mechanical wave will be entered vertically and depending on time has not been considered in all this simulating. FDA is in medical equipment measurement such as HIFU as a standard resource so is considered standard. If we consider HIFU simulating software in FDA based on a kidney tissue which its dimensions and weight aren't clear and just its acoustic impedance and input wave are clear, below results will be obtained for that that among this obtained pressures are important. In figure 8 which is based on FDA simulating for kidney tissue that in peak time has 12 megapixel input pressure in simulating with mechanical model because of not being with time, lack of accuracy in collision point and only accuracy in thickness, the amount of pressure will be 8.85 mega Pascal. It means almost 35% error in achieving pressure and it can be expressed that with combining these two models and better incorporation of mechanical model and FDA and with availability of lab's facilities, the accuracy in pressure measuring can be improved(9).

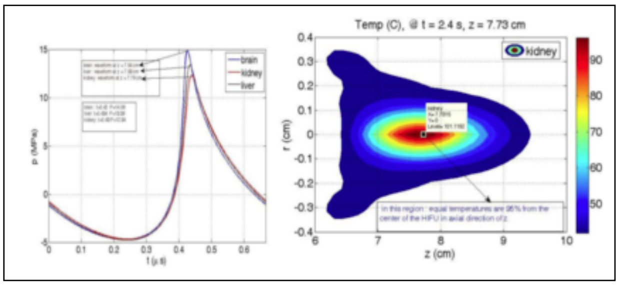

Figure 8: The Simulation result of FDA software by one kidney slice.

Discussion

Let's notice the layer model of figure 9, the outermost layer of body will be obtained that pressure and heat leave the most amount of their value on skin. N ultrasound waves will enter tissue from skin. According to formula:

$$I = I_0 . \exp(-\mu * z)$$

μ linear attenuation coefficient, z depth and I is the Sound intensity that is this formula intensity and its thickness will be reduced in each layer gradually. If the amount of pressure or heat isn't calculated in outermost layer, it leads to tissue's burning or tissue damage. For preventing tissue damage, the intensity and time of sound passes from outside must be set.

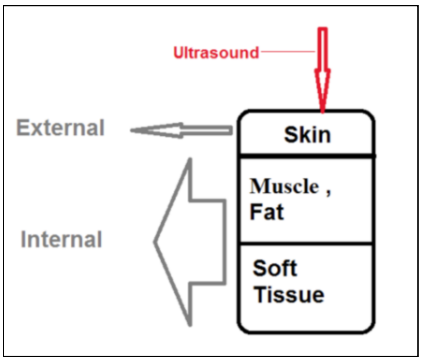

Figure 9: The similarity of obtained phantom with the real shape of body's inside.

In order to this, mechanical model of figure 3 was first used to be applied considering tissue waves characteristics. Because we weren't able to access a real HIFU system and a human tissue in this model, we used a kidney and in the next step a sheep's liver inside phantom figure 6. In these entire steps variable wasn't considered with the time. We hope to consider time more in future experiments for more accuracy. Software FDA was used due to lack of real access.

Conclusion

We used a sheep's kidney tissue with clear dimensions, after dividing that to determined layers with determined dimensions, obtained its strain stress values, placed those values inside designed mechanical model then applied ultrasound waves to that as mechanical wave. In this model we obtained the amount of pressure in each layer using existing pressure sensors and compared that with HIFU simulating software in site FDA. The two model were compared considering that in our project, viscoelastic weight and properties of tissue are paid attention and in FDA model just the kind of tissue in terms of acoustic impedance and the speed of sound in tissue are noticed. In this comparison pressure values in our model rather to FDA has an error about 12% that the big amount of this error might be related to simulating error and the kind of comparison which is very important and can be removed in clinical experiments. This comparison is considered for avoiding tissue damage. In fact in HIFU the amount of pressure gradually will be reduced but the existence of the phenomenon of superposition causes much more pressure in final or tumor place which is tried that total general effects with this model is paid attention in future projects.

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